

The M4.5V flare star AF Psc as seen in K2 engineering data

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ABSTRACT

We present the light curve of the little studied flare star AF Psc (M4.5V) obtained using engineering data from the K2 mission. Data were obtained in Long Cadence mode giving an effective exposure of 29 min and nearly 9 d of coverage. A clear modulation on a period of 1.08 d was seen which is the signature of the stellar rotation period. We identify 14 flares in the light curve, with the most luminous flares apparently coming from the same active region. We compare the flare characteristics of AF Psc to two M4V flare stars studied using *Kepler* data. The K2 mission, if given approval, will present a unique opportunity to study the rotation and flare properties of late type dwarf stars with different ages and mass.

Key words: Physical data and processes: magnetic reconnection – stars: activity – Stars: flares – stars: late-type – stars: individual: AF Psc, KIC 5474065, KIC 9726699

1 INTRODUCTION

NASA’s *Kepler* mission was launched in March 2009 and spent the next 4 years making near continuous flux measurements of over 160,000 stars in an area of sky covering 115 square degrees in the constellations of Cygnus and Lyra (Borucki et al. 2010). Although the prime science driver for the mission was the discovery of Earth sized planets around Solar type stars, it provided a wealth of information on objects as diverse as pulsating stars, accreting systems, supernovae and flare stars. With the loss of two of the satellites four reaction wheels, the mission has now evolved into the K2 mission (Howell et al. 2014). Funding permitting, this will result in a series of pointings along the ecliptic plane, each lasting ~ 75 days. In the planning stage for the K2 mission, several engineering tests are being made. Data from the Feb 2014 tests have recently been made publically available.

The pointing of the original *Kepler* was such that the pointing accuracy was much better than the pixel scale on a timescale much shorter than the three month quarters (Koch et al. 2010). In the K2 mission, by pointing at fields in the ecliptic plane, photon pressure from the Sun acts as the only source of force and the two remaining reaction wheels remove the build up of angular momentum. This causes the stars to shift by measureable amounts on the CCD detectors. However, the *Kepler* team found that K2 gives photometry which is within a factor of 2–4 of the original *Kepler* data (see Howell et al 2014).

The almost continuous light curves which *Kepler* is able to provide makes it ideal for the investigation of many types

of phenomena including stellar flares. For instance, Balona (2012) reported observations of flares from stars with early A and F spectral types, while Maehara et al. (2012) and Shibayama et al. (2013) report ‘super-flares’ from Solar type stars. At lower masses, Walkowicz et al (2011) made a study of flares from cool stars and Gizis et al. (2013) reported flares from an L dwarf. In Ramsay et al. (2013), we reported observations of two M4V stars which showed intense flare activity. Here we report on observations derived from K2 engineering data on another flare star, AF Psc.

2 AF PSC

AF Psc was discovered as a high amplitude (>6 mag) flare star nearly 40 years ago (Bond 1976). It was included in a large spectroscopic sample of nearby M dwarfs and a spectral type of M4.5V was determined and a distance of 11 pc derived by parallax measurements (Riaz, Gizis & Harvin 2006). AF Psc is around the same brightness ($V=14.4$) as KIC 9726699 ($g=13.9$) but much brighter than KIC 5474065 ($V=18.1$) both of which were studied by Ramsay et al (2013). It does not appear to have been the subject of a previous dedicated optical photometric study, although several flares in the UV were observed on AF Psc using Galex (Welsh et al. 2006). These authors also reported the detection of oscillations on a timescale of ~ 30 sec during flares, which they interpreted as being due to ‘slow sausage mode’ waves.

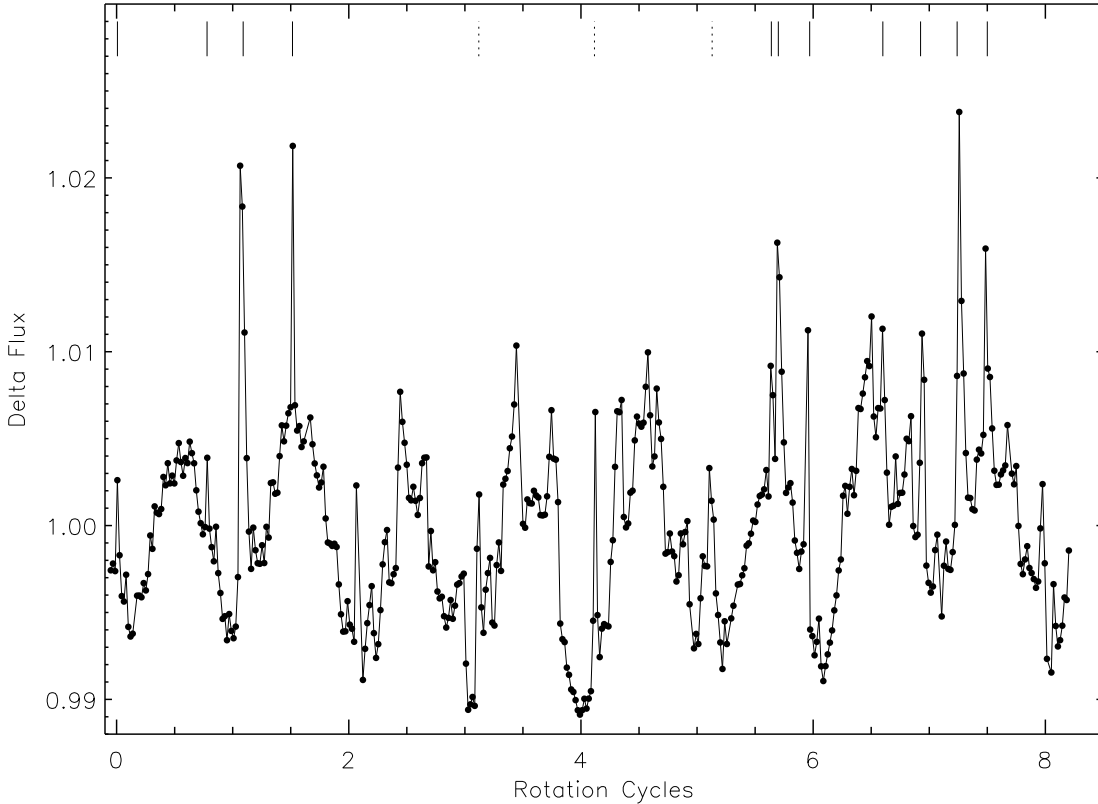


Figure 1. The light curve of AF Psc made using K2 in engineering data where each point has an effective exposure of 29 min. The data has been phased ($\phi=0.0$ is defined by minimum flux) on the 1.08 day period which is clearly present in the data. The vertical lines at the top of the panel note the time of flares in the light curve. The three consecutive flares occurring at $\phi \sim 0.12$ are noted by dashed vertical lines.

3 K2 DATA

The detector on board *Kepler* is a shutterless photometer using 6 sec integrations and a 0.5 sec readout. The observations of AF Psc were made in *long cadence*, where 270 integrations are summed for an effective 29.4 min exposure. This contrasts with the observations made of the two M4V targets KIC 5474065 and KIC 9726699 (Ramsay et al 2013) which were made in *short cadence* where the effective exposure is 58.8 sec.

Observations were carried out in engineering tests from MJD 56692.57 to 56701.50 (2014 Feb 4th to Feb 13). The coverage was therefore 8.9 days in duration. During this time interval there were frequent thrusts of the spacecraft to ensure pointing accuracy with one large shift occurring on MJD 56694.86 (or 2.3 days into the time series).

A 50×50 pixel array is downloaded from the satellite for each target. To extract a light curve of AF Psc we used the PyKe software (Still & Barclay 2012)¹ which was developed for the *Kepler* mission by the Guest Observer Office. We experimented by extracting data from a series of different combinations of pixels. We found that a mask centered on AF Psc, but including a relatively faint (USNO-B1 gives $R \sim 18.9$) nearby (~ 20 arcsec) star consisting of 140 pix-

els gave the optimal results. If a smaller number of pixels are used we find that there are small discontinuities present in the light curve which is the result of small shifts in the position of the stellar profile over the CCD. We also experimented with subtracting the background (which increased in a nearly linear fashion over the course of the observations) in different ways. We found that using the median value of each time point to represent the background gave the best results. Finally we removed time points which were not flagged ‘SAP_QUALITY==0’ (for instance times of enhanced solar activity).

4 RESULTS

We normalised the extracted light curves by dividing the data by the mean background subtracted flux. The light curve of AF Psc shows a clear modulation on a period of 1.08 ± 0.08 days (Figure 1). Given AF Psc is an M4.5V star, this modulation is caused by the rotation of spots or active regions on the photosphere. The first few rotation cycles have smooth profiles, but then become more complex (double horn shaped at maximum) which indicates that active regions appear and disappear on relatively short timescales.

In Ramsay et al. (2013), we used an automatic routine to identify flares in the *Kepler* data of two M4V stars. Given the quality of the present light curve is relatively lower (and

¹ <http://keplergo.arc.nasa.gov/PyKE.shtml>

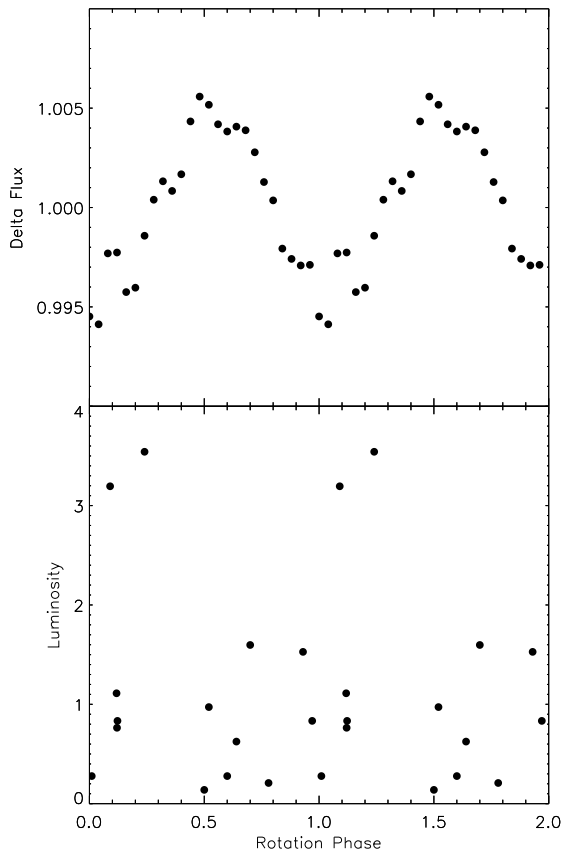


Figure 2. Top Panel: The light curve of AF Psc phased and binned on the rotation period of 1.08 days. Lower Panel: The energy of the flares plotted as a function of rotation phase.

the time coverage much shorter) we decided to manually identify flares in the light curve of AF Psc. We searched for events which showed a rapid rise in flux and an exponential decline which is characteristic of stellar flares. Given each exposure is 29 min, very short duration flares are likely to either be missed completely or seen as a flux increase in only one time point. We were rather conservative in identifying points as flares and did not (for instance) flag the enhanced flux point at 2.05 rotation cycles (Figure 1) as this coincided with a significant shift in the stellar profiles. In some cases it was rather subjective whether an event was a flare or not – for instance we did not identify features in rotation cycle 2 (Figure 1) as flares, but rather the general variation seen in the rotation curves of active stars. We identified 14 flares in AF Psc (which are marked in Figure 1) over the whole 9 days of data.

To determine the luminosity of the flares we assume that a star with spectral type M4.5V has an luminosity $L = 2.5 \times 10^{30} \text{ erg s}^{-1}$ (see Ramsay et al 2013 for details). We then sum up the area in the flare assuming this base luminosity. Given we do not use any model for the flare profile and that the time resolution is rather low, there is some degree of uncertainty in the estimate for each individual flare. However, it does indicate the general characteristics of the flare behaviour of this source. We find that the flares seen in AF

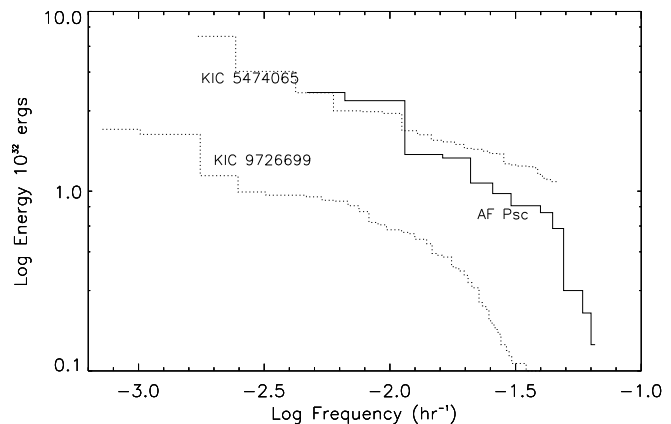


Figure 3. The cumulative energy distribution of flares (in the Kepler band-pass) as seen in AF Psc, KIC 5474065 and KIC 9726699.

Psc have a luminosity in the range $\sim 0.1 - 3.0 \times 10^{32} \text{ erg}$ in the Kepler band-pass. This compares to $L = 1.1 - 7.3 \times 10^{32} \text{ ergs}$ for KIC 5474065 and $L = 0.01 - 2.2 \times 10^{32} \text{ ergs}$ for KIC 9726699.

We show the folded and binned light curve of AF Psc in Figure 2 together with the rotation phase and luminosity of each flare. We note that the most luminous flares were seen between $\phi=0.1-0.3$. Indeed, in Figure 1 it is seen that there are three consecutive rotation cycles where a flare is seen at $\phi \sim 0.12$. This indicates that there is a region on the star which is active over more than one rotation cycle.

We show the cumulative flare-frequency distribution in Figure 3 for AF Psc and KIC 5474065 and KIC 9726699. Interestingly, despite being a more rapid rotator than KIC 5474065 (1.08 d compared to 2.47 d), the flare-frequency distribution of these sources are very similar. The distribution of AF Psc goes to lower luminosities since it is a much brighter source (and hence less luminous flares may have been missed in KIC 5474065). In contrast, KIC 9726699, although having a very similar spectral type (M4V) is a more rapid rotator (0.59 d). AF Psc does not show the high amplitude flares seen in KIC 5474065 but this maybe due to the shorter timeline of the data (8.9 d compared to 24.2 d) and the longer exposure time for each photometric point.

5 CONCLUSIONS

If the K2 mission proceeds as hoped, it will cover a number of clusters (Howell et al 2014) which have ages ranging from the very young (Taurus-Auriga Association at 2 Myr), to the not-so-young (the Pleiades at 125 Myr) to the positively old (M67 at 3.6 Gyr). The engineering data presented here of AF Psc demonstrate that K2 has the photometric accuracy to identify the rotation period and flare rate of M dwarf stars even in long cadence mode and over a time interval significantly shorter than that planned for K2 in full operation. K2 will give an unique opportunity to determine how the stellar rotation period and flare rate of late type dwarfs are effected by age, mass and metallicity. West et al (2008) showed that a marked change in activity levels occurs

around the spectral type M4. K2 will allow the the determination of key observables for dozens of stars with spectral type in the range M0–M8 and hence address the underlying physical reasons for this.

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REFERENCES

- Balona, L., 2012, MNRAS, 423, 3420
 Bond, H. E., 1976, IBVS, 1160
 Borucki, W. J. et al., 2010, Sci, 327, 977
 Gizis, J. E., Burgasser, A. J., Berger, E., Williams, P. K. G., Vrba, F. J., Cruz, K. L., Metchev, S., 2013, ApJ, 779, 172
 Howell, S. B., et al., 2014, accepted PASP, (arXiv:1402.5163)
 Koch, D. G., et al., 2010, ApJ, 713, L79
 Maehara, H., Shibayama, T., Notsu, S., Notsu, Y., Nagao, T., Kusaba, S., Honda, S., Nogami, D., Shibata, K., 2012, Nature, 485, 478
 Ramsay, G., Doyle, J. G., Hakala, P., Garcia-Alvarez, D., Brooks, A., Barclay, T., Still, M., 2013, MNRAS, 434, 2451
 Riaz, B., Gizis, J. E., Harvin, J., 2006, AJ, 132, 866
 Shibayama, T., Maehara, H., Notsu, S., Notsu, Y., Nagao, T., Honda, S., Ishii, T. T., Nogami, D., Shibata, K., 2013, ApJS, 209, 5
 Vidotto, A.A., Jardine, M., Opher, M., Donati, J.F., Gombosi, T.I., 2011, ASPC 448, 1293
 Walkowicz, L. M., et al 2011, AJ, 141, 50
 Welsh, B.J., et al., 2006, A&A 458, 921
 West, A.A., Hawley, S.L., Bochanski, J.J., Covey, K.R., Reid, I.N., Dhital, S., Hilton, E.J., Masuda, M., 2008, AJ 135, 785